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Smart power grid and cloud computing☆

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A B S T R A C T

As a consequence of rapidly increased CO_2 emissions, humanity is facing global warming. Electricity generation accounts for almost half of the emission; besides, conventional electrical production based on fossil fuel is becoming more and more expensive. One approach to significantly slow down global warming is to drive our society away from the current fossil fuel fiesta and use only renewable power such as solar and wind energy. Another approach is to improve the management of energy production, transmission, and distribution. Part of the latter solution is on the supply side, where one possible solution is to develop continent-wide smart power grids and energy storage systems. However, an equally important part of the solution is on the demand side, where technologies and applications that can work with this type of unpredictable energy consumption are becoming necessary. The smart power grid with new sources of data, fast growth of information, and proactive management requires new strategy for business and operational management. In this paper we discuss how Cloud computing model can be used for developing Smart Grid solutions. The Cloud computing model is based on the delivery of computing as a service, whereby storage, software and information are provided to computers and other devices as a commodity over the Internet. The advantages of Cloud computing – reduced costs, increased storage, on-demand performance, and better flexibility – have motivated many companies in recent years to move their IT operations to the cloud; the same advantages can be used to achieve the most important future goals of a large-scale Smart Grid, such as energy savings, two-way communication, and demand resource management.

Contents

1. Introduction

It is almost impossible to imagine the world we live in without electricity. Economic development and sustainability of humanity is conditioned by industrialization that constantly requires more

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and more energy. In the last decade of industrial development, the world economy is moving away from cheap energy to consumption of expensive energy. Awareness of the relative limitations of the traditional exhaustion of energy resources on the one hand, and limited energy supply from renewable energy sources have a dual effect on the energy and economic development, but also on the environment.

Electricity is a pivotal element for understanding global energy challenges. It is an energy carrier, a sort of intermediary, between the supply of primary energy sources (e.g. coal) and the demand for energy-using services (e.g. transport, heating, and lighting). Electricity is, in fact, *the* main energy carrier used around the world for residential, commercial, and industrial processes next to fuels and heat. The climate challenge related to electricity stems from the fact that over two-thirds of global electricity production is generated from the combustion of fossil fuels [1].

Globally, it is expected for residential/commercial demand to continue shifting *toward* electricity and *away* from the primary fuels used directly by consumers. The need for energy to make electricity will remain the single biggest driver of demand. By 2040, electricity generation will account for more than 40 percent of global energy consumption [2].

In the past decade, electricity demand was rising more quickly than utility companies could keep up with. Besides, conventional electrical production based on fossil fuels is becoming more and more expensive, while at the same time consumers are becoming increasingly concerned about greenhouse gases resulting from fossil fuel energy production. Consumer demands are also responding to economic and environmental pressures by demanding a granular view of their real-time usage and time-of-day pricing.

Energy based on fossil fuels was developed a hundred years ago, and it is unlikely that it will appear more economically feasible than new technologies in the near future. That "old" energy will not just as easily give way to new energy due to environmental protection [3]. The current approach to invest in large scale centralized fossil fuel power plants is obviously not working anymore. The cost of main natural resources of conventional grid power (coal and copper) is rising, while on the other hand the cost of renewable energy sources such as solar panels and LEDs is falling down even faster. Therefore, investing in large scale centralized energy production, particularly coal plants, seems relying on the wrong tool for much of the job, not to mention the waste of scarce resources. That leaves us with many reasons to invest in the alternative—distributed, clean, and renewable energy access.

The growing importance of energy sustainability imposes the need to monitor and control the optimal usage of energy assets. Smart power grids with their support for real-time, two-way communication between utilities and consumers come to a rescue. Although the term smart power grid cannot be uniquely defined, it usually implies a network able to intelligently connect all users involved (generators, markets, service providers, distributors, customers, appliances etc.) to deliver sustainable, economic, and secure electricity supply. The smart power grid is a melting pot of different technological trends and engineering platforms; furthermore, since the concept itself is relatively new and evolving, the relevant terminology is not yet settled down. Smart grids offer many advantages, among which the most notable are increased energy efficiency, information availability, better fail recovery, and the possibility of using alternative energy sources.

Cloud computing is also a general term, referring to convenient, on-demand network access to a shared pool of configurable computing resources (networks, servers, storage, applications etc.) that can be quickly provisioned and released with minimal management effort or service provider interaction [25]. Cloud installations can use techniques such as virtualization to separate the software from the characteristics of physical servers. Using this approach it is often possible to optimize servers and reduce energy costly features. The emergence of cloud computing is providing a fundamentally different IT model in which a cloud provider might be responsible for a range of IT activities, including hardware and software installation, upgrades, maintenance, backup, data storage, and security.

Cloud platforms can play important role in software architectures that allow more effective use of smart grid applications. Specifically, cloud computing services can address needs for large scale real-time computing, communication, transfer and storage of data generated by Smart Grid technologies.

This paper provides information on recent developments in application of Cloud technologies with the existing power grid. We present a broad overview of the state of the art in this area and discuss possible research directions to achieve better interaction between Smart Grid and Cloud computing model.

The remainder of this paper is organized as follows: Section 2 presents a system view of the Smart Grid. Section 3 details the design and developmental issues of Cloud computing. Section 4 presents state of the art in applying Cloud technology in Smart Grids. Finally, Section 5 concludes with a discussion of future trends of the Cloud in the smart power grid environment, and discusses key problems to be solved. This paper closes with a glossary of the relevant terminology.

2. Smart grid

To better understand the term smart power grid, which means different things to different people depending on the perspective of their own area of expertise or interest, we should look at it as a whole. Before we continue with the explanation of the new paradigm, we present a short overview of the conventional power grid. We continue with highlighting the differences and advantages of smart grid over conventional electric grid, and then conclude with discussing two important smart grid design features where Cloud platforms can be efficiently applied, namely integrating time-dependent renewable resources (virtual power plants) and controlling the load.

2.1. Conventional electric grid

Electric power systems (EPS) are real-time energy delivery systems. Real-time means that power is generated, transported, and supplied the moment the light switch is turned on. Electric power systems are not storage systems like water systems and gas systems; instead, a power grid is a perfect just-in-time system where generation and demand must be balanced at every instant.

The system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable for efficient long-distance transportation [6].

High-voltage power lines in the transmission portion of the electric power system efficiently transport electrical energy over long distances to the consumption locations. Finally, substations transform this high-voltage electrical energy into lower-voltage energy that is transmitted over power lines that are more suitable for the distribution of electrical energy to its destination, where it is again transformed for residential, commercial, and industrial consumption. The distribution network includes medium-voltage (less than 50 kV) power lines, substation transformers, pole- or pad-mounted transformers, low-voltage distribution wiring and electric meters. The distribution system of an electric utility company may have hundreds of substations and hundreds of

thousands of components, all managed by a distribution management system (DMS) [6,8].

Traditional electric power systems are composed of two key components [9]:

- Business Management System (BMS): handles business management functions like Customer Relationship Management (CRM) and Billing system.
- Energy Management System (EMS): composed of tools supporting the operator to manage daily energy flow activities and to make effective decisions.

Of special interest is an EMS component called SCADA (supervisory control and data acquisition), which provides control and monitoring of electrical devices to EMS system. SCADA systems monitor energy flow in different points of the generation, transmission and, to some extent, distribution stage of energy and relay back the information to a control center operator that takes necessary actions to keep demand and supply in electric balance. The information about consumption is in the form of meter data used to generate the bills for the customer.

In this producer controlled model, power flows in one direction only. There is no two-way communication that allows interactivity between end users and the grid. Experts argue that traditional electric grid technologies are no longer supporting the demands of a growing population and that emphasis on investing in newer, more efficient technologies is a key element in ensuring a sustainable future for mankind [7].

2.2. Smart power grid definition

The reliability of electric power system is a vital parameter for power delivery and economic development for every community. Today, operation of traditional power system is limited in interoperability across applications. The information in these areas is usually provided for local networks only and not on real time basis; this results in a new challenge for high power quality, reliability, availability, and security.

Since traditional electric grid is not capable of providing mentioned functionalities, science community and utility companies are working together on a new concept of “intelligent” or “smart” electric grid. This so called Smart Grid uses large numbers of networked sensors, power electronic devices, distributed electricity generators, and communications appliances. In such a way, electric grid becomes smarter and more complex, but requires integration of large quantity of real-time information and data processing. According to [10], the “smartness” in the Smart Grid will have to ensure the balance of generation and demand in the presence of time-varying and stochastic (random) generation and demand influences, which is a substantial departure from the deterministic paradigm of today's grid. Integrating these new applications and technologies while still ensuring the stability of a perfect just-in-time system will require the addition of new control, monitoring, and protection mechanisms.

The smart power grid consists of a large and wide ranging set of many services, applications, equipment, networks and systems that act together in delivering the “intelligent” or “connected” grid in order to maintain security and control, communications, leisure and comfort, energy efficiency, environmental integration and accessibility. These components are represented by many actors that interact and work together to provide interactive systems that benefit the community.

NIST Framework and Roadmap for future Smart Grids [11] identifies seven *domains* within the Smart Grid: *Transmission*, *Distribution*, *Operations*, *Bulk Generation*, *Markets*, *Customer*, and *Service Provider* (Fig. 1). According to NIST definition, smart grid domain is a high-level grouping of organizations, buildings, individuals, systems, devices, or other *actors* with similar objectives and relying on—or participating in—similar types of applications. Across the seven domains, numerous actors capture, transmit, store, edit, and process the information necessary for Smart Grid applications.

As illustrated in Fig. 1, the NIST Framework shows that future smart grids should support the following two flows:

- *Electrical* (*power*) *flows* (generation, transmission, and distribution of energy)
- *Information processing flows* (collecting, processing, and distributing data).

The information flow in a smart grid has a twofold objective:

- to monitor and control the flow of energy (similar to classical SCADA systems) and
- to monitor and control future and new energy based services.

Electric utilities are currently focusing their efforts on three major areas of the smart grid with the strongest business case justification [5]:

- Delivery Optimization: efforts to improve the efficiency and reliability of the delivery systems.
- Demand Optimization: solutions to empower the end consumer and to better manage the evolving demand and supply equation along the distribution chain.
- Asset Optimization: application of monitoring and diagnostic technologies to help manage the health, extend the useful life, and reduce the risk of catastrophic failure of electrical infrastructure.

Over the past decade, expansion, deregulation, and increased market competition changed the energy delivery system architecture for the energy sector. Asset owners and operators extended the connectivity of their energy delivery systems to improve communication and increase system efficiency. They increasingly adopted commercial off-the-shelf technologies that provided higher levels of interoperability required among their system components [12].

These additional requirements exceed the capabilities of the existing grid, however, and cannot be achieved by simply modifying the current supervisory control and data acquisition (SCADA) network. Smart Grid communications network must incorporate new design features that address two major requirements: integrating time-dependent renewable resources and controlling the load. These two requirements will be influenced by the introduction of new, dynamic end-use technologies: virtual power plants and load balancing (demand response management) systems. In these two Smart Grid priority areas Cloud systems can be especially usable, as we will discuss in Section 3.

2.3. Virtual power plants

Energy integration makes it possible for erratic and inconsistent renewable power sources to play a bigger role in meeting peak energy demand. Smart grids, capable of gathering real-time feedback on electric supply and demand, help reduce peak load and enable the integration of solar, wind, fuel cells, and other power sources. Most studies confirm that an intermittent renewable energy contribution of up to 10–20% can easily be absorbed in electricity networks [14].

In order to handle distributed generation and to intensify its visibility within power markets, the idea of virtual power plant

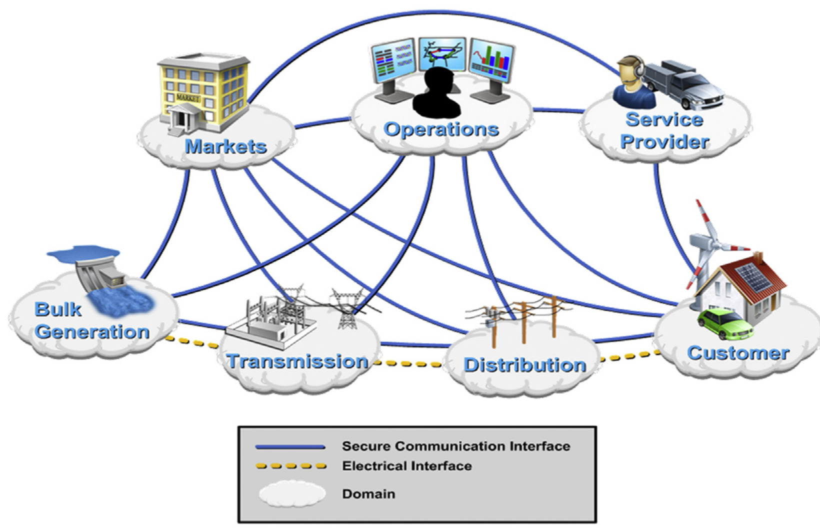

Fig. 1. NIST conceptual model for Smart Grid [11].

(VPP) has emerged and is used by many researchers. Virtual power plant is composed of combining various small size distributed generating units to form a "single virtual generating unit" that can act as a conventional one and is capable of being visible or manageable on individual basis.

Analogous to what happens when server virtualization software is used in data centers, smart utility companies are turning to intelligent software to make more efficient use of their resources. The benefit for utility companies conducting such efforts is that they have more available power capacity. In this case, instead of building a new power plant (or two) to get that additional capacity, a utility company essentially has created a VPP.

As its name implies, a virtual power plant does not exist in the concrete-and-turbine sense. Rather, it uses the Smart Grid infrastructure to tie together small, disparate energy resources as if they were a single generator. Just about any energy source can be linked up, and energy that is *not* used can also contribute to a virtual power plant's capacity.

The unused electricity can then be aggregated by the virtual power plant, along with other actual energy resources, and sold to customers who need power during peak times. Without the virtual power plant, the utility company's only other option for meeting peak loads is to ramp up production, which can get very expensive.

A virtual power plant also lets smaller energy producers take part in energy markets from which they might otherwise be excluded. One plant set up by Siemens aggregates 1450 MW of capacity from small generators installed in hospitals, industrial facilities, and commercial buildings throughout Germany. Ordinarily, each of these units would be used only during emergencies and only to power its particular site. Hooked up via the virtual power plant, they can now be fired up whenever market rates or grid conditions make it worthwhile [15].

Pike Research estimates that the worldwide capacity of virtual power plants could grow from 45 GW in 2010 to as much as 105 GW by 2017, with revenues of about $6.5 billion [16].

In much the same way that social networks drill through user data, i.e. use data mining techniques to discern subtle patterns in people's taste and then try to influence their buying habits, virtual power plants give grid operators the means to study their customers' electricity usage and then try to get them to modify their behavior in a way that increases the capacity of the virtual power plant [15, 16].

2.4. Demand-response management

The ability to optimize energy usage at all levels of the supply chain will become an important sustainability issue. Smart energy management systems are key enablers of the envisioned efficiencies both on the demand and supply sides of the smart energy grids. On the demand side, they aim at supporting end-users in optimizing their individual energy consumption, e.g., through the deployment of smart meters providing real-time usage and cost of the energy and the use of demand-response appliances that can be switched on/off at a given time depending on the user preferences, energy cost and carbon footprint. On the supply side, the smart grid management systems aim at optimizing the network load, quality and reliability of the energy provision, e.g. thorough active monitoring and prediction of the energy usage patterns, and proactive control of the reliable energy delivery over the network. It is also envisaged that they will be able to influence the demand through the dynamic adjustments of the energy price in order to influence the end-user behavior and energy usage patterns [18].

It is important to realize that electricity users do not want electricity alone. They want a service, such as transportation, lighting, water, welding, motor movement, communication, or warmth. The success of the electricity supply must be judged by the availability, quality, and cost of the service. The quality of a service (e.g., heating or water supply) tends to be measured by an intensive parameter (e.g., temperature or pressure) and the availability of that parameter. The cost of the service is measured by an extensive parameter (e.g., energy or kilowatthours) linked to its availability. The desire for the service presents a demand on the grid system, which power engineers see as load.

Satisfactory service can be maintained without the continuous consumption of electricity. For instance, water of a satisfactory temperature can be supplied from a previously heated tank. If the value of the intensive parameter is maintained (i.e., shower temperature), the consumer is satisfied even if electrical supply is interrupted. A demand that is satisfied by intermittent power is an interruptible load, also called a switchable load. If load and tariff management are used to optimize a power system (e.g., to increase the penetration of renewable energy), it is quite acceptable to use it to induce new trends in energy use [19].

Most utility companies are becoming proactive in recognizing and responding to grid and network communication problems. Problems should be recognized and fixed before customers become

aware of them. To accomplish this, monitoring grid devices and meters, managing the information flow, correlating events across systems, monitoring services, and controlling critical services must accurately follow the state of the grid and its supporting infrastructure.

Renewable sources are variable resources that produce power on their own schedule and cannot be controlled by system operators to match supply and demand. One of the best smart grid's features is the ability to balance variable sources by shifting demand around (demand response), harnessing diversity, and installing electricity storage.

Demand response [13,46] refers to changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.

Sending price signals is one of the best ways to do this, but there are other, older approaches, such as allowing the utility company to control customer loads directly. These “direct load control” programs work well, but as the cost of price signaling keeps dropping and the smart grid era dawns, the use of prices to induce customers to change their load rather than controlling them directly is gaining favor. Using SMS, Internet, smart appliances or intelligent smart meters, customers can be warned one day in advance, so they can make plans to shift their use the next day. Deployment of smart meters means that utility companies and customers gain robust and two-way communication. In such a way both parties can understand how much energy is being consumed and utility companies can send not only load control signals to devices but also the current price of electricity [20].

Demand-response management saves money for both a utility company and its customers by reducing the need for generation capacity and minimizing the amount of energy the utility company must purchase on the open market at peak demand periods.

3. Cloud computing

Cloud computing is a term that denotes hosted online services. These services are accessed via the Internet, which is metaphorically referred to as a “cloud”. Cloud computing has received a growing amount of attention in recent years due to its promising computing service delivery model that requires a limited amount of resources on the customer's side. The broad scope of cloud computing is all about where the computing resources reside, who manages them, and how are they accessed and paid for. Cloud installations can use virtualization to separate the software from the characteristics of physical servers. By using this approach it is often possible to optimize servers and reduce certain energy costly features.

Most people are already interacting with various types of cloud computing services. For example, an email account with the Web-based email service Gmail, instead of running an email program on the computer, logs the user in his email account remotely. The software and storage for the account do not exist on the computer —they are on the email service provider's computer cloud.

Various factors have contributed to more and more widespread use of cloud computing, including the increased availability of broadband Internet, improved technologies such as virtualization, and new models to deliver web-based services. The cloud computing provider business model is based on supplying infrastructure consisting of large pools of high-performance computing resources and high-capacity storage devices that are shared among the services offered by the provider [21]. Customers subscribing to the services have their data hosted by the provider, and have computing resources allocated on demand from the pool as required. The cloud computing provider's offering may also extend to the software applications required by the customers. To be successful, the Cloud computing model also requires a high-speed network to provide connection between customers and the cloud computing provider's infrastructure.

Cloud computing offers economic incentives to companies because they can reduce IT spending and benefit from more flexibility and scalability. An overall financial benefit is also potentially increased by significant savings in the energy budget of a company. Traditionally, each company would have its own dedicated *data centers* with their own servers, software applications and development platforms. These have to be paid for, managed and maintained internally. There are high capital expenditures associated with purchasing the hardware and software, and it can be time intensive updating and maintaining these systems. These data centers are often underutilized as they must have the capacity to cope with the highest levels of processing needs, which usually happens very rarely.

Benefits of cloud computing have much to do with the economies-of-scale that cloud computing providers can achieve. Instead of having in-house computing resources for each company, one cloud computing provider delivers services to multiple companies by sharing its resources. Resource sharing concept allows computing resources to be exploited much more efficiently compared to in-house computing resources. More diverse remote users in different places allow for computing loads to spread over the day, thus allowing for increased equipment utilization. Cloud installations also have a substantial advantage by having departments devoted to efficiency. Technology changes so rapidly that it is hard for people not devoted to efficiency to keep up as well as those that are.

Some large companies have adopted a *private cloud* approach, which means that they have consolidated all their disparate servers and applications into one company wide system which is maintained behind their firewall and can be accessed across their intranet, i.e. they are sharing their resources between the different offices and business units. This means that they can make better, more efficient use of their resources because they are being shared by more people. It also means that their systems are uniform across the company.

However, the colloquial term cloud computing usually refers to *public clouds*, whereby companies buy necessary services from specialist cloud computing providers. Instead of owning and managing their own data centers, companies access the services they bought from anywhere via the Internet. Customer relationship management systems of a company, for example, may be run by one cloud computing provider and the information is stored in the provider's data centers, while the company's email system may be run by another cloud computing provider. These services can be provisioned remotely, quickly and in an on-demand, self-provisioned manner and the company pays only for what it needs and uses.

Cloud computing is not a universal solution. It has strengths and weaknesses, and understanding them is key to making a decision about whether it is right for a particular need.

Main advantages of cloud computing are the following:

- Economy of scale: sharing of computing resources between different customers
- Pay per use: customers pay for the service instead of buying software licenses and hardware
- On-demand usage/flexibility: cloud services can be used almost instantly and can easily be scaled up and down
- External data storage: customers' data are stored externally at the location of the cloud computing provider
- Highly reliable services: clouds manage themselves in case of failures or the performance degradation.

On the other hand, the most cited weaknesses of cloud computing are:

- Dependency on Internet connectivity: a constant connection is required
- Loss of control: someone else is hosting hardware, software and data, which can raise security concerns
- Unpredictable cost: pay per use means that the cost of computing will be different every month

The cloud computing service model is a sound business model from both provider's and customer's perspectives. Providers invest in the necessary infrastructure and management, and in return receive a regular income stream from the investment by means of service subscriptions [22]. Since at any given time substantial numbers of customers are inactive, the provider reaps the benefits of the economies of scale and can charge lower subscription fees. The customers in turn see convenience benefits from having data and services available from any location, from having data backups centrally managed, from the availability of increased capacity when needed, and from usage-based charging [23, 24].

Cloud computing model can be broken down into three segments: “software”, “platform” and “infrastructure”. Each segment serves a different purpose and offers different products to businesses and individuals around the world. The fundamental, practical services of cloud computing are known as

- *software as a service* (SaaS)
- *platform as a service* (PaaS—sometimes called middleware)
- *infrastructure as a service* (IaaS—sometimes called Hardware-as-a-Service) [25].

IaaS gives a consumer the control over a particular type of operating system, storage, database, networking, and applications deployed on the cloud. The PaaS provides the consumer with the ability to deploy applications, but denies the possibility to manage or control the underlying cloud infrastructure. A PaaS simplifies the process of software development by an order of magnitude, but may not be as flexible as IaaS because some of the details are hidden from the end user. Finally, SaaS allows the consumer to use the provider's applications running on a cloud infrastructure, usually through a thin client interface, such as a web browser. In SaaS environments, the cloud vendor has complete control over the application, including capabilities, updates, and maintenance.

Cloud computing is rapidly expanding as an alternative to conventional in-house computing because cloud computing offers significant efficiency and cost advantages. Large economic advantages (driven by the energy advantages) of cloud services will over time translate into more and more pressure for companies to adopt them. To deliver technical and economic advantage, cloud computing must be deployed, as well as implemented, successfully. Deployment supersedes implementation, because merely utilizing the services of a cloud vendor does not by itself differentiate an organization from its competitors [56].

For the sake of clarity, it is worth mentioning that the term *grid computing* is often confused with cloud computing; although these terms have a lot in common, they are also quite different. Grid computing uses the resources of numerous computers in a network to work on a single problem at the same time. Cloud computing evolves from grid computing and provides on-demand resource usage. In summary, grid and cloud computing are both scalable, but only cloud technology offers on-demand applications and resources [26].

4. Applications of cloud computing in the smart grid environment

In this section we will examine opportunities of using cloud platforms in the domain of energy informatics.

Information Technology (IT) has a significant role to play in the smart grid space. Industries like banking, telecom and other business suites have already recognized the importance of information and data management using IT and now the energy companies will have to follow the same approach. As utility companies are deploying the smart meters and smart grid solutions, the role of IT will grow and will become one of the essential elements for utility companies. IT plays an important role not only in transformation of the utility company–customer relationship, but also in providing solutions and key information to utility companies to manage, control and monitor the electrical network in most efficient and effective way [27, 28].

IT is becoming an important part of the transformation of network operations as utility companies exploit new data sources in order to improve network efficiency. New capabilities are emerging based on large-scale information management, real-time data analysis, and the move to closed-loop systems for managing, monitoring, and controlling the smart grid. Applications such as outage management and asset management are also being radically overhauled by the integration of IT and operational technology [17].

NIST document [25] identifies eight priority areas which are urgently required from the smart grid:

1. Demand response and consumer energy efficiency
2. Wide-area situational awareness
3. Energy storage
4. Electric transportation
5. Network communications
6. Advanced metering infrastructure (AMI)
7. Distribution grid management
8. Cybersecurity

Next, we will discuss how cloud computing fits as a solution or an auxiliary means to achieve some of the mentioned priorities.

4.1. *Cloud computing and large-scale transfer and storage of data*

Globally deployed smart grid infrastructure will need information technology (IT) support to integrate data flow from numerous appliances, to predict power usage and respond to events. Cloud platforms are ideally suited to support such data intensive, always-on applications.

The need for large scale real-time computing, communication, transfer and storage of data generated by smart grid technologies is expected to be addressed by cloud computing services. Some recent papers such as [29] indicate that flexibility and scalability of storing and processing large amounts of data and cost savings are some of the major benefits of using cloud solutions for smart grid applications.

Utility companies can use cloud model to store and process large quantities of data collected from smart meters and appliances, as well as sensors deployed across the smart grid. According to [30], cloud platforms are an intrinsic component in creating software architecture to drive more effective use of smart grid applications. The primary reason is that cloud data centers can accommodate the large-scale data interactions that take place on smart grids and are better architected than centralized systems to process the huge, persistent flows of data generated across the utility value chain.

Bulk data for demand-response analysis in smart grids comes from sensors and smart meters, and is transmitted in different intervals (from few seconds to several hours) by using Internet protocols. Since smart grid applications are distributed, a smart grid cloud must support different platforms with efficient streaming technologies. At present, Cloud providers do not provide specialized data abstractions for streams, other than TCP sockets. An open research field is stream processing in public and private clouds, and across diverse platforms.

One of the most important features of Smart Grid is a two-way communication with consumers; according to [13], most of the ongoing activity in the Smart Grid communication is currently in the Consumer domain. Smart devices have started to reach the consumer market but the interoperability and complete solution for Smart Grid is still far away.

4.2. Cloud computing and software services for smart grid

Which of the available cloud service models mentioned before (SaaS, PaaS, or IaaS) will be used for Smart Grid applications such as AMI, SCADA, EMS depends on availability, flexibility, maintenance, portability, and security that a utility company expects. If a utility company already has a software package to install and run in the cloud, then the obvious solution is IaaS; if there is no software or the solution must be built from scratch to solve a problem, then the company should try a PaaS.

Although all the three models may be adopted by utility companies depending on their need and the state of the development of smart grid, the current trend is towards the SaaS. In this hosted software model, the cloud infrastructure hosts the application and data in central server; the utility companies access the application and data over the Internet and pay on a monthly subscription basis.

Applications like AMI, MDMS, DMS (distribution management system), volt/VAR optimization, and outage management are suitable candidates for SaaS approach. It is expected that AMI EMS system will be the first one to be available in this model; others, such as the outage management application, still wait to be implemented in real world.

As more and more utility applications are becoming candidates for the cloud model, big vendors like IBM, Microsoft, Cisco, Oracle, SAP, GE, ABB and Schneider are attracted into the SaaS fray.

For example, Verizon [31] announced a partnership with eMeter to offer cloud-based meter data management for utility companies. The service leverages Verizon's IP network to deliver scalable meter data management. Itron [32] is working with IBM, SAP and Teradata to set up a meter data warehousing and analytics system for Southern California Edison. Telvent and Microsoft [33] are working together to provide utility companies with cost-effective, scalable, performance-oriented solutions that leverage key aspects of Microsoft's platform technologies. Aclara, which controls many of the consumer engagement sites for utility companies, has also long been using the cloud. General Electric has taken it a step further in a project with Norcross, GA, to do various distribution automation services via the cloud [34]. GE Digital Energy is building a host of applications – AMI, GIS, MDMS, distribution management, volt/VAR optimization, outage management, asset management and more – under the banner Grid IQ: Solutions as a Service. It offers them in three flavors so that utility companies can host the data and the applications, host the data only or implement the applications on the utility company's own computers [35].

One of the most common applications for real-time data in manufacturing and process industries is SCADA, supervising remote processes over a network. With the growing popularity of cloud computing, many engineers and managers in the automation sector are looking at the possibility of using the cloud for SCADA.

SCADA systems have evolved over time and have followed the progress of computing in general. As many view cloud computing as the next logical step in this evolution, enthusiastic visionaries foresee a fourth, "cloud" generation of SCADA, where an entire control system would be running in the cloud [36]. The cloud is creating a revolution in SCADA system architecture because it provides very high redundancy, virtually unlimited data storage, and worldwide data access—all at a very low cost [40].

Cloud computing can support SCADA applications in two ways:

- The SCADA application is running on-site, directly connected to the control network and delivering information to the cloud where it can be stored and disseminated. The control functions of the SCADA application are entirely isolated to the control network. However, the SCADA application is connected to a service in the cloud that provides visualization, reporting, and access to remote users. These applications are commonly implemented using public cloud infrastructures (PaaS cloud service).
- The SCADA application is running entirely in the cloud and remotely connected to the control network. The controllers are connected via WAN links to the SCADA application running entirely in the cloud. These applications are commonly implemented using private or hybrid cloud architectures (IaaS cloud service).

IaaS enables service provider customers to deploy and run off-the-shelf SCADA software as they would on their own IT infrastructure. IaaS provides on-demand provisioning of virtual servers, storage, networks, and other fundamental computing resources. Users only pay for capacity used, and can bring additional capacity online as necessary.

SCADA vendors have been slow to adopt the SaaS service model for their core applications. This may change as the uncertainty of cloud computing begins to clear. For now, vendors are beginning to release only certain SCADA application components and functions as SaaS, such as visualization and historical reporting.

SCADA system is dependent upon the bandwidth and latency of cloud service's Internet service provider, as well as of company's Internet connection. In order to obtain acceptable performance for certain manufacturing applications, high bandwidth networks with low latency may be required. SCADA system data are usually dependent on real-time monitoring and control, so loosing this functionality for even a few seconds or minutes can wreak havoc on production departments. The only way to decide if moving to the cloud is the right choice for a company is to evaluate risks involved in its own SCADA system. There is no single right answer; each situation has to be evaluated on its own terms [37–39].

The final consideration in software for Smart Grid relates to a problem of presenting real-time energy usage and power pricing information to consumers through web portals, for which the cloud platform is also suitable. Data collected and integrated from various sources should be accessible to intelligent applications for customized consumer needs, and communicated to external entities. Clouds provide a ready platform for data sharing and also allow third-party applications to integrate the data source. However, scalable access to this data will have to balance the need for open access to identified data with performance of critical, demand-response applications.

4.3. Cloud computing and energy savings

The energy consumption of the cloud computers should be controlled in order to optimize the energy consumption for a

specific computing effort. Techniques like shutdown, hibernate, or sending in different low power stages are current areas of analysis in order to achieve more "green" computation [41].

Many studies have found that cloud computing is a more energy-efficient choice in general compared to running in-house IT operations. The studies confirm that among other benefits, cloud computing delivers multiple efficiencies and economies of scale, which contribute to the reduction of energy consumption per unit of work.

Report [42] released by Pike Research anticipates that much of the work done today in in-house data centers will be outsourced to the cloud by 2020. This will lead to a 38% reduction in worldwide data center energy expenditures by 2020, thanks to a reduction of 31% in data centers electricity consumption (from 201.8 terawatt hours (TWh) in 2010 down to 139.8 TWh in 2020).

Another report [43], released by research firm Verdantix, estimates that cloud computing could enable companies to save $12.3 billion off their energy bills. That translates into carbon emission savings of 85.7 million metric tons per year by 2020.

The findings from a study [44], commissioned by Microsoft and conducted by Accenture and WSP Environment & Energy, demonstrate that businesses that choose to run business applications in the cloud can help reduce energy consumption and carbon emissions per user by a net 30% or more versus running those same applications on their own infrastructure. The reduction goes even to as much as 90% for the smallest and least efficient businesses.

However, other studies have also found that cloud computing is not always the most energy efficient computing option, and under some circumstances cloud computing can be more energy intensive than traditional in-office computing. In [21], it is found that cloud computing can indeed save energy, but looking at three different applications of cloud computing – storage, software, and processing – energy efficiency savings are negated in some instance. For example, one scenario when cloud computing may consume more energy than conventional computing is when companies use cloud computing for storing data and when the number of downloaded and accessed files becomes larger.

4.4. Cloud computers as virtual power plants

When we look for energy, expenses and CO_2 reduction, we need to look in parallel to the cloud computer entity which aggregates the power of the computer components, as well as the energy consumed by each computer which can be aggregated in a virtual distributed consumer, connected to the power network in various places, many times supplied by different suppliers, connected to different distributors and acting simultaneously in different countries [41].

Cloud computers are energy consumers able to modulate their consumption based on the actual tasks. For instance, if only 60% of the general computing power is used, then a part of the physical machines can be shut down, thus reducing the overall power consumption of the cloud computer. An important feature is related to the energy consumption which can be controlled by using specialized software dedicated to cloud computer. With this functionality, cloud computers can act as flexible consumers.

An important aspect is that in the virtual power plant concept, not only generators are considered resources, but also the flexible consumers, as the cloud computer can be. Moreover, the cloud computer is not only a possible flexible consumer, but also its consumption is already aggregated and controlled by the cloud computer software, so it acts like a virtual power plant.

Existing cloud systems as consumers and energy systems as producers are independent systems which usually work in parallel, with limited interaction during the one-way power supply task. Such parallel networks need more complex interaction in order to achieve better overall performance. This way, some features of both systems may become synergic. On one hand, the load that is provided by the cloud computer centers offers a confident image about the consumption demand. On the other hand, the low power demand periods can be used to spend the extra energy for the production of cooling medium inside the cloud computer centers. This kind of thermal energy storage system offers a very effective method of cutting electric power costs for owners and easing demand on the power grid [45]. The model is comparable with life subsystems (blood system, nervous system, muscular system) whose mutual interactions allow for their high performance, economic operation and high reliability.

Smart Grid should be responsive to the current load on the power system. The computational cost of algorithms to reduce power demand will depend on the latency requirements and the amount of load to curtail. The execution and scheduling model for such applications will need to plan the availability of Cloud resources accordingly since the elasticity of the Cloud comes with an overhead. This planning may include starting additional virtual machines as the power begins to peak, or increasing cumulative bandwidth capacity to support higher sampling rate of streaming data. These execution policies will also have to intelligently use available computing capacity at the private Cloud and clusters available with the utilities, and make dollar cost tradeoff of enlisting additional computing power in commercial Clouds against the KW or power curtailed.

5. Clouds and smart grids: state of the art and future challenges

Neither the energy nor the computing grids of tomorrow will look like yesterday's electric power grid. The smart power grid with new sources of data, fast growth of information, and proactive management requires new technologies to support it.

The three major risk factors to consider for Cloud based Smart Grid system are security, performance, and reliability. Many of the benefits of Clouds come with their own set of challenges, several of which are unique to the Smart Grid domains. We highlight some of problems to be solved in the future here.

Security is a major issue for electrical companies. From a risk-analysis perspective, the company may suffer repercussions if any data entrusted to the cloud is compromised. When company information is located in the cloud, it is more difficult to trace the hackers than it would be if the hackers broke into the internal system. With Cloud services control on how the security is set up is lost, which leaves solution of security problems entirely in the hands of Cloud service.

Selective movement of data hosted on private Clouds at the utility to the public storage space on-demand will have to be supported. Also, typical public Cloud storage platforms do not provide fine grained authorization control for data. Models for using the shared Cloud repository by multiple users and their software agents, with different levels of access, need to be examined. It is also important that the Cloud provider has an efficient replication and recovery mechanism to restore data if a disaster occurs.

With the massive amounts of data and information expected to flow across utilities with the implementation of smart grid technologies, the data collection and analysis centers at the utilities themselves can become points of failure, resulting in loss of information system network connectivity. Yet, in the context of Smart Grid, it is now more critically important than ever for utilities to be able to share information for wide-area and real-time system analysis and visualization. Advanced distributed

communications tools can provide the security needed for wide-area situational awareness of the grid network.

Risks considering performance and reliability include the following [38]:

- If performance fluctuates, how will that affect the company?
- How will latency and latency variability affect customer's experience?
- How much latency is acceptable?
- What if the system goes down for a few hours?
- If the system goes down, will important data be lost?

The open research problem is how to build the smart synergy between energy components and IT System from Cloud computation system to smart terminal through existing telecommunications lines. With thousand of objects capable of and willing to cooperate, it is impossible to apply the traditional approaches, especially considering the side-effects such as the unnecessary network utilization. Therefore further investment should be done towards a Cloud publish/subscribe model, where the necessary entities can subscribe and get only the events/commodity interesting for them.

Modeling of demand response with a large number of participants is still a challenge. For Smart Grid implementations, there is a need to move the industry from manual to optimized and adaptive demand response management by partitioning consumers into clusters and alleviating privacy concerns. The use of Cloud distributed infrastructure can help achieve this goal.

The very important task in the nearest future will be to network the interested parties in order to accelerate innovations in energy storage research and their implementation in practice. There are still no mature offerings from energy-sector providers, although opportunities exist to leverage cloud in energy markets where costs, technology complexity and time to market are major issues.

Because of wide ranging variability of the entities in Smart Grids, there is a very high level of potential complexity in finding the optimal solution for each different Smart Grid. Smart Grid will eventually be deployed across all types of infrastructure using widespread Internet of Services, connecting all smart objects worldwide. It will become the major application domain of the Internet of Things, perhaps even referred to as the Internet of Energy.

6. Glossary

Advanced Metering Infrastructure (AMI) typically refers to the full measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas, or water utility, and data reception and management systems that make the information available to the service provider [4].

Agents are sophisticated computer programs that act autonomously on behalf of their users, across open and distributed environments, to solve a growing number of complex problems. Increasingly, however, applications require multiple agents that can work together.

Appliance is a piece of equipment (tool or device) designed for a particular practical use or function.

Asset Optimizations the application of monitoring and diagnostic technologies to help manage the health, extend the useful life, and to reduce the risk of catastrophic failure of electrical infrastructure [5].

Automated Meter Reading (AMR) refers to the technology used for automating collection of water and energy (electricity or gas) consumption data for the purposes of real-time billing and consumption analysis. At any given time, the AMR system gathers real-time data and transfers the information gathered to the central database through networking technology [47].

Business Process Management (BPM) is a methodology for reducing the complexities of multiple processes and for empowering business users to react to changing needs, and support decision-making [48].

Cloud Computing is a new consumption and delivery model for IT services. The broad scope of cloud computing is all about where the computing resources reside, who manages them and how are they accessed and paid for. Users can consume services at a rate that is set by their particular needs. Most of the time cloud computing is concerned with accessing online software applications, data storage, and processing power. Cloud computing is broken down into three segments: “software”, “platform” and “infrastructure”. Each segment serves a different purpose and offers different products to businesses and individuals around the world.

Communication Technology includes the principal data transmission and network technologies, like wired and mobile telephony, radio broadcast, wired and wireless data transmission.

Connectivity is, in the most general terms, the ability to connect systems or application programs. Ideally, these connections are established without requiring many changes to the applications or the systems on which they run. For example, device can use multiple networks to connect to the Internet or other devices, and it can seamlessly switch over to another network if the previous network becomes unavailable or a more suitable network becomes available. Gateways and converter modules can be used to connect an incompatible device to another network type, but ultimately it is applications and their interoperability that determine how compatible systems are connected with each other.

Data Mining is the process of analyzing data from different perspectives and summarizing it into useful information. Data analysis finds pattern and rules that can be used to guide decision making and predict future behavior [48].

Delivery Optimization consists of the efforts by the electric utility to improve the efficiency and reliability of the delivery systems [5].

Demand Optimization focuses on solutions to empower the end consumer and to better manage the evolving demand and supply equation along the distribution feeder [5].

Demand Response (DR) is the program that transfers customer load during periods of high demand to off-peak periods and can reduce critical peak demand (the 20–50 hours of greatest demand throughout the year) or daily peak demand (the maximum demand during a 24-hour period). Shifting daily peak demand flattens the load curve, allowing more electricity to be provided by less expensive base load generation [49].

Demand-Side Management (DSM) is a set of interconnected and flexible programs which allow customers to play a greater role in shifting their own demand for electricity during peak periods, and reducing their energy consumption overall. DSM programs comprise two principal activities, demand response programs or “load shifting”, on one hand, and energy efficiency and conservation programs on the other [49].

Distributed Generation (DG) is an approach that employs small-scale technologies to produce electricity close to the end users of power. DG technologies often consist of modular (and sometimes renewable-energy) generators, and they offer a number of potential benefits. In many cases, distributed generators can provide lower-cost electricity and higher power reliability and security with fewer environmental consequences than can traditional power generators [50].

Distribution Management System (DMS) is a central component to implementing Smart Grid. DMS enables utility companies to manage distributed renewable generation, implement grid efficiency improvement measures, and control the isolation and restoration of outages. With DMS, the utility company gets abundant real-time information about the distribution grid, including the non-telemetered feeder circuits. Utility companies rely heavily on DMS to improve distribution grid reliability and efficiency [51].

Energy Management System (EnMS) is a systematic process for continually improving energy performance of energy consumers. It is suitable for all organizations, but is particularly beneficial if they operate energy-intensive processes. The term should not be confused with the same term used mainly in relation to energy producers: an **energy management system (EMS)** is a system of computer-aided tools used by operators of electric utility grids to monitor, control, and optimize the performance of the generation and/or transmission system. The monitor and control functions are known as SCADA; the optimization packages are often referred to as "advanced applications".

Equipment refers to not only the "end-user-devices" (computers and peripherals, digital data recorder-storage-player devices, modems, phones and multimedia mobiles, fax machines, set-top boxes and TV and peripherals), but also to the "infrastructure" that consist of both hardware and software elements (server and data centers, wired core telecom networks, cellular phone networks, Wireless Local Area Networks, Radio/TV broadcast equipment and micro-systems).

Future Internet (FI) is a holistic communication and information exchange ecosystem, which will interface, interconnect, integrate and expand today's Internet, public and private intranets and networks of any type and scale, in order to efficiently, transparently, interactively, flexibly, timely, and securely provide services (including essential and critical services) to humans and systems, while still allowing for tussles among the various stakeholders without restricting considerably their choices [52].

Grid usually refers to a network, and should not be taken to imply a particular physical layout or breadth.

Grid Computing is a network infrastructure for coordinated resource sharing used for solving a single problem.

Infrastructure as a Service (IaaS) is a cloud service in which an organization outsources the equipment used to support operations, including storage, hardware, servers, and networking components. The service provider owns the equipment and is responsible for housing, running, and maintaining it. The client typically pays on a per-use basis.

Information Technology (IT) encompasses all aspects of computer-related systems, be it the computer hardware, software, data, programming, multimedia, networks, and so on. Information technology is now a global industry, a college degree, a field of study, a professional occupation, and is used on a daily basis by millions of people.

Internet of Energy (IoE) is a dynamic network infrastructure that interconnects the energy network with the Internet allowing units of energy (locally generated, stored, and forwarded) to be dispatched when and where it is needed. The related information/data will follow the energy flows thus implementing the necessary information exchange together with the energy transfer [52].

Internet of Services (IoS) is a software based component that is delivered via different networks and Internet. Research on Web/enterprise 3.0/X.0, enterprise interoperability, service Web, grid services and semantic Web will address important bits of the IoS puzzle, while improving cooperation between service providers and consumers [17].

Internet of Things (IoT) is an integrated part of future Internet including existing and evolving Internet and network developments. It could be conceptually defined as a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual "things" have identities, physical attributes, and virtual personalities, use intelligent interfaces, and are seamlessly integrated into the information network [17].

Interoperability is capability of two or more networks, systems, devices, applications or components to exchange and readily use information, securely, effectively, and with little or no inconvenience to the user.

Meter Data Management Systems (MDMS) are suite of software programs that receive and store meter data, and support a host of revenue cycle and other functions (e.g., billing, outage management, and distribution engineering) [53].

Outage Management System (OMS) is a computer system used by operators of electric distribution systems to assist in the restoration of power. An outage management system based on GIS integrates all essential data—from SCADA systems, customer information, work orders, and the electric network.

Platform as a Service (PaaS) is a way to rent hardware, operating systems, storage, and network capacity over the Internet. The service delivery model allows the customer to rent virtualized servers and associated services for running existing applications or developing and testing new ones.

Prosumer refers to the dual role of an energy entity by being both an energy generator and an energy user. The term "prosumer" emphasizes this as the combination of the terms "producer" and "consumer".

Quality of Service (QoS) attempts to objectively measure the service delivered by the vendor. QoS measurement for most of the time is not related to customer, but to media/commodity. It is tied closely to the black and white of a contract and measures how well the vendor lives up to its end of the bargain.

Software as a Service (SaaS) is a software distribution model in which applications are hosted by a vendor or service provider and made available to customers over a network, typically the Internet.

Sensors are input devices that detect environmental changes, user behaviors, human commands etc.

Services are the final product of ICT including the respective hardware, software, and individual media contents. ICT services can be defined as computer based (data- and media-processing, computer-aided design (CAD) and computer simulations), telecom-based (teleworking, shopping and conferencing), internet-based (e-business, e-commerce, e-government and e-learning), and GPS-based (navigation, traffic control, security and rescue systems).

Smart Power Grid is a type of electrical grid which attempts to predict and intelligently respond to the behavior and actions of all electric power users connected to it (suppliers, consumers and those that do both) in order to efficiently deliver reliable, economic, and sustainable electricity services. It refers to the application of digital technology to the electric power sector to improve reliability, reduce cost, increase efficiency, and enable new components and applications.

Smart Home is a residence that has appliances, lighting, heating, air conditioning, TVs, computers, entertainment audio and video systems, security, and camera systems that are capable of communicating with one another and can be controlled remotely by a time schedule, from any room in the home, as well as remotely from any location in the world by phone or internet.

Smart Meters are innovative and advanced utility meters that record a business or consumers energy, water or gas usage in real time and in greater detail than current conventional meters.

Smart Objects are objects that are designed to tailor their responses to their virtual environment, providing a "sense-and-control loop" that works to optimize resources, productivity, and quality.

Supervisory Control and Data Acquisition (SCADA) is a category of software application programs for process control and data gathering in real time from remote locations in order to control equipment and conditions. SCADA is used in power plants as well as in oil and gas refining, telecommunications, transportation, and water and waste control. SCADA warns when conditions become hazardous.

Sustainable development is the development that meets the needs of the present without compromising the ability of future generations to meet their own needs.

Virtualization is the creation of a virtual (rather than actual) version of something, such as an operating system, a server, a storage device or network resources. There are three areas of IT where virtualization is making main progress: network virtualization, storage virtualization and server virtualization. The usual goal of virtualization is to centralize administrative tasks while improving scalability and workload.

Virtual Power Plant (VPP) is the network of several small power stations (a cluster of distributed generation installations, such as microCHP, wind-turbines, small hydro, back-up gensets etc.) that are run like a single system [54].

Voltage and VAR Optimization (VVO) is an advanced application that runs periodically or in response to operator demand, at the control center for distribution systems or in substation automation systems. Combined with two-way communication infrastructure and remote control capability for capacitor banks and voltage regulating transformers, VVO makes it possible to optimize the energy delivery efficiency on distribution systems using real-time information [55].

Wireless Sensor Network (WSN) is a wireless network consisting of spatially distributed autonomous devices that use sensors to monitor physical or environmental conditions. These autonomous devices, or nodes, combine with routers and a gateway to create a typical WSN system. The distributed measurement nodes communicate wirelessly to a central gateway, which provides a connection to the wired world where you can collect, process, analyze, and present your measurement data [48].

References

[1] Mickoleit AOECD. ICT applications for the smart grid: opportunities and policy implications, OECD Digital Economy Papers, No. 190. OECD Publishing, http://dx.doi.org/10.1787/5k9h2q8v9bln-en; 2012
[2] The outlook for energy: a view to 2040. Exxon Mobil Corporation, 〈http://www.exxonmobil.com/Corporate/files/news_pub_eo.pdf〉; 2012.
[3] Hordeski M. F. Megatrends for energy efficiency and renewable energy. The Fairmont Press, Inc., ISBN: 0-88173-632-5; 2011.
[4] Advanced Metering Infrastructure (AMI). Electric Power Research Institute; 2007.
[5] Flyn, BR. Grid, key smart applications, 〈http://www.smartgridnews.com/artman/uploads/1/Smart_Grid_Applications.pdf〉.
[6] Blume SW. Electric power system basics for the nonelectrical professional. IEEE Press, Published by John Wiley & Sons, Inc.; ISBN 978-0-470-12987-6; 2007.
[7] Digambar MT. Electric power Generation: the changing dimensions, Wiley-IEEE Press, ISBN: 978-0-470-60028-3; 2011.
[8] Philipson L., Lee Willis H. Understanding electric utilities and de-regulation, CRC Press, ISBN: 0824727738; 〈http://dx.doi.org/10.1201/9781420028263〉; 2005.
[9] Shahid H. Coordination and monitoring services based on service level agreements in smart grids, PhL. Thesis. Blekinge Institute of Technology (BTH); 2012.
[10] Interview with Stefano Galli, 〈http://smartgrid.ieee.org/〉.
[11] NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 1.0. NIST Special Publication 1108, 〈http://www.nist.gov/public_affairs/releases/upload/smartgrid_interoperability_final.pdf〉; 2010.
[12] Roadmap to achieve energy delivery systems cybersecurity, 〈http://www.cyber.st.dhs.gov/wp-content/uploads/2011/09/Energy_Roadmap.pdf〉.
[13] Usman A, HaiderShami S. Evolution of communication technologies for smart grid applications. Renewable and Sustainable Energy Reviews 2013;19:191–9.
[14] Smart grid information report, Enerweb, 〈http://www.enerweb.co.za/brochures/Smart%20Grid%20Information%20Report.pdf〉; 2011.
[15] Kumagai J. Virtual power plants, real power. IEEE Spectrum 2012;49(3):13–4.
[16] Virtual Power Plants, 〈http://www.pikeresearch.com/research/virtual-power-plants〉.
[17] Smart Grid IT Systems, 〈http://www.pikeresearch.com/research/smart-grid-it-systems〉.
[18] Smart Energy Management, 〈http://www.swinburne.edu.au/ict/success/research-projects-and-grants/smart-energy/〉.
[19] Farret FA., Simões MG. Integration of alternative sources of Energy, John Wiley & Sons, ISBN 978-0-471-71232-9; 2006.
[20] Fox-Penner P. Smart power—climate change, the smart grid, and the future of electric utilities. Island Press; 2010.
[21] Baliga J, Ayre RWA, Hinton K, Tucker RS. Green cloud computing: balancing energy in processing, storage and transport. Proceedings of the IEEE 2011;99(1):149–67.
[22] Buyya R, Yeo CS, Venugopal S. Market-oriented cloud computing: vision, hype, and reality for delivering IT services as computing utilities. In: Proceedings of the 10th IEEE international conference high performance computing communications. IEEE; 2008. p. 5–13.
[23] Weiss A. Computing in the clouds. NetWorker 2007;11(4):16–25.
[24] Hayes B. Cloud computing. Communications of the ACM 2008;51(7):9–11.
[25] The NIST definition of cloud computing, 〈http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf〉; 2011.
[26] Foster I, Zhao Y, Raicu I, Lu S. Cloud computing and grid computing 360-degree compared. In: Proceedings of the grid computing environments workshop (GCE'08). IEEE; 2008. p. 1–10.
[27] Dynamic communications for smart grid. Alcatel-Lucent, 〈http://enterprise.alcatel-lucent.com/private/images/public/si/pdf_powerUtilities.pdf〉; 2010.
[28] Transforming the energy value chain, 〈http://www.corpevents.fr/docs/DOC-IBM-WP_Transforming_Energy_Value_Chain.pdf〉; 2011.
[29] GlobalData's report "Cloud Computing—Key Enabler of Smart Grid"; 2011.
[30] Kumar A. Redefining smart grid architectural, thinking using stream computing, Cognizant 20-20 Insights. Cognizant; 2011.
[31] Verizon teams with eMeter to enable meter data management from the cloud, http://newscenter.verizon.com/press-releases/verizon/2011/verizon-teams-with-emeter-to.html; 2011.
[32] Geschickter C. How Itron plans to capture the smart grid big data opportunity, 〈http://www.greentechmedia.com/articles/read/how-itron-plans-to-capture-the-smart-grid-big-data-opportunity/〉; 2011.
[33] Microsoft and Telvent: taking outage management to the next level, 〈http://download.microsoft.com/download/F/1/F/F1FF8201-A9BB-403B-BF F5-A6EE238ECD30/Telvent_Responder_web%20version_Final.pdf〉; 2011.
[34] Tweed K. Smart grid has its head in the cloud, 〈http://www.greentechmedia.com/articles/read/smart-grid-has-its-head-in-the-cloud/〉.
[35] Smart Grid GE. Solutions, underline move to cloud computing, 〈http://energy.aol.com/2012/01/09/ge-smart-grid-solutions-underline-move-to-cloud-computing/〉.
[36] McIlvride B. Will SCADA evolve to the cloud? 〈http://real-timecloud.com/2012/05/03/will-scada-evolve-to-the-cloud/〉.
[37] Birman KP, Ganesh L, Van Renesse R. Running smart grid control software on cloud computing architectures, In: Proceedings of the workshop on computational needs for the next generation electric grid. Ithaca; 2011.
[38] Cloud-based SCADA systems: the benefits & risks. inductive automation. White Paper; 2011.
[39] McIlvride B. SCADA and the cloud—FUD and facts, 〈http://real-timecloud.com/author/realtimecloud/〉; 2012.
[40] Combs L. Cloud computing for SCADA, 〈http://www.controleng.com/single-article/cloud-computing-for-scada/8a6ea192e60cc626d2e3fc3a5686396d.html〉; 2011.
[41] Borza Paul Nicolae, Sanduleac Mihai, Catalin Carp Marius, Puscas Ana Maria. Energy and information, Engineering the future, Dudas Laszlo (Editor), ISBN: 978-953-307-210-4, InTech, Available from: 〈http://www.intechopen.com/books/engineering-the-future/energy-and-information〉.
[42] Cloud computing energy efficiency, 〈http://www.pikeresearch.com/research/cloud-computing-energy-efficiency〉.
[43] Cloud computing—the IT solution for the 21st century. Carbon Disclosure Project, 〈https://www.cdproject.net/en-US/WhatWeDo/Pages/Cloud-Computing.aspx〉.
[44] Cloud computing and sustainability: the environmental benefits of moving to the cloud, 〈http://www.microsoft.com/environment/cloud.aspx〉.
[45] Fournier Eric. Using thermal energy storage for data center cooling. The Fortress International Group, 〈http://www.missioncriticalmagazine.com/ext/resources/MC/Home/Files/PDFs/Using_Thermal_Energy_Storage.doc〉.
[46] Assessment of demand response and advanced metering. Federal energy regulatory commission reports; 2010.
[47] Li L, Xiaoguang H, Jian H, Ketai H. Design of new architecture of AMR system in smart grid. In: Proceedings of the sixth IEEE conference on industrial electronics and applications (ICIEA). IEEE; 2011. p. 2025–9.
[48] Wireless Sensor Network Topologies and Mesh Networking, National Instruments, White Paper, 〈http://www.ni.com/white-paper/11211/en〉, 2010.
[49] Aghaei J., Alizadeh M. Demand response in smart electricity grids equipped with renewable energy sources: a review, Renewable and Sustainable Energy Reviews, Volume 18, February 2013, Pages 64–72, 〈http://dx.doi.org/10.1016/j.rser.2012.09.019〉.
[50] Ackermann T, Andersson G, Soder L. Distributed generation: a definition. Electric Power Systems Research 2001;57(3):195–204.
[51] Pilo F, Pisano G, Soma G. Advanced DMS to manage active distribution networks. In: Proceedings of the IEEE Bucharest powertech conference. Bucharest: Romania. IEEE; 2009. p. 1–8.

[52] Kortuem G, Kawsar F, Fitton D, Sundramoorthy V. Smart objects as building blocks for the Internet of things. IEEE Internet Computing. IEEE 2010;14(1): 44–51.
[53] Deciding on “Smart” meters: the technology implications of Section 1252 of the Energy Policy Act of 2005. Edison Electric Institute, ⟨http://www.eei.org/ourissues/electricitydistribution/Documents/deciding_on_smart_meters.pdf⟩.
[54] Virtual power plants for renewable energies, ⟨http://www.siemens.com/innovation/en/news/2012/e_inno_1212_1.htm⟩.
[55] Feng X, Peterson W. ABB, North Carolina USA, Volt/VAR optimization reduces losses, peak demands, ⟨http://www.electricenergyonline.com/?page=show_article&mag=61&article=466⟩.
[56] Garrison G, Kim S, Wakefield RL. Success factors for deploying cloud computing. Communications of the ACM 2012:62–8.